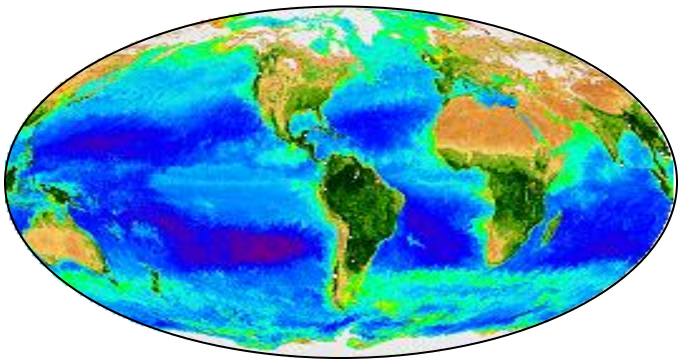
A Satellite View of Ocean Ecosystems and Carbon

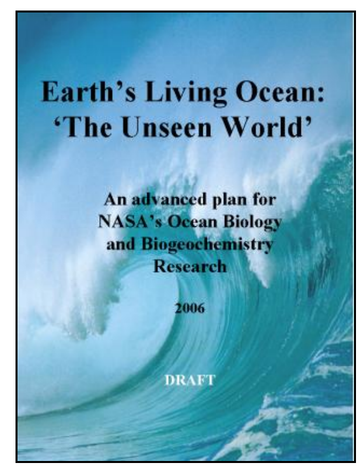
Michael J. Behrenfeld
Oregon State University

Evolving Science



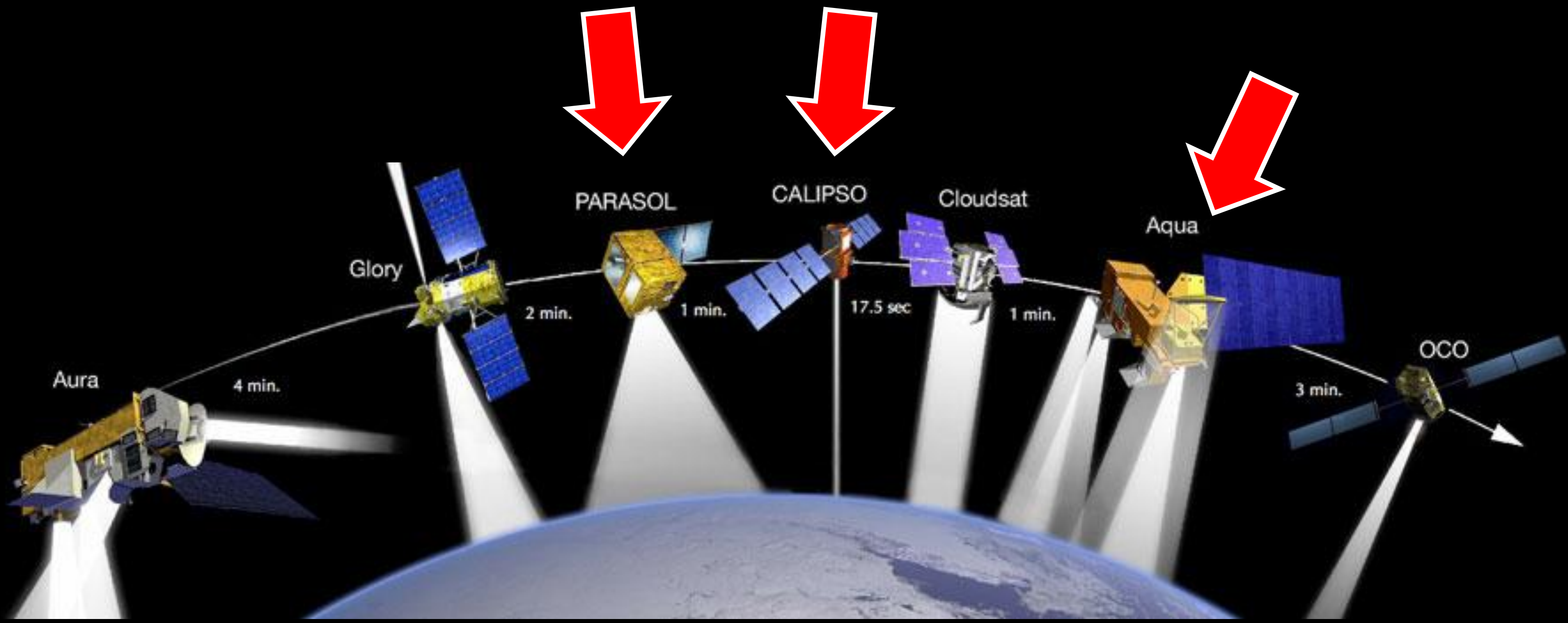
'Beyond Chlorophyll'

- ***Ecosystem Stocks & Composition***
  - Particulate and dissolved constituents; Organic and inorganic
  - Dominant planktonic and abiotic forms
- ***Material Flow through Ecosystems***
  - Uptake of CO_2 through photosynthesis (~50 Pg y^{-1}); Carbon flow between upper ocean pools; Carbon export to depth
- ***Ecosystem Health***
  - How fast are organisms growing?
  - What limits ecosystem productivity – 'bottom-up' or 'top down'?
- ***Ecosystem Change***
  - How do observed ecosystem changes reflect functioning of the 'Earth System'?
- ***Events & Challenging Regions***
  - Harmful algal blooms; Unique & ecologically important species; Coastal & inland waters



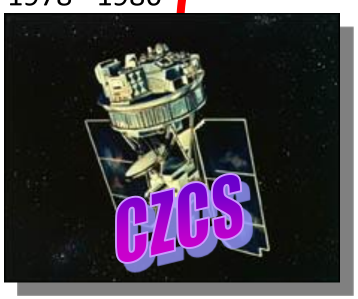
Ocean Ecosystems & the A-Train

- **Primary instrument is *MODIS-Aqua***
- **Additional ocean research with *CALIPSO* and *PARASOL* (**potential future applications of *Glory***)**



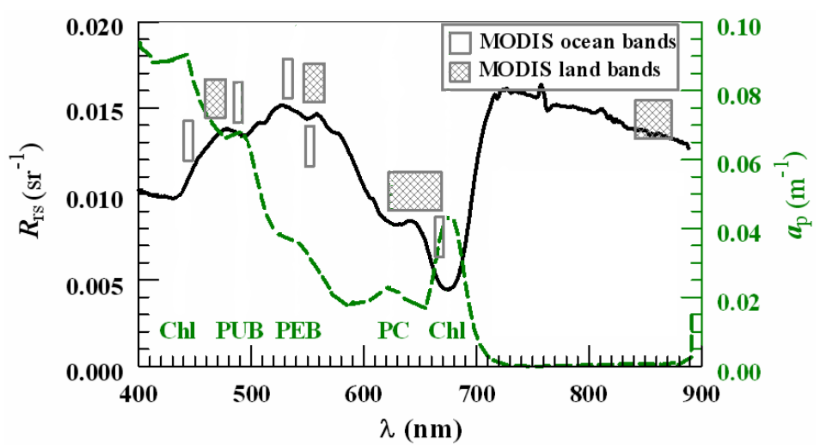
NASA Ocean Color Heritage

1978 - 1986

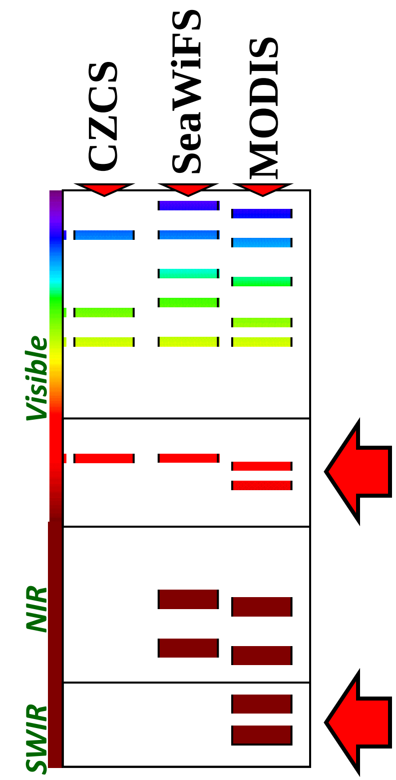


1997 - present

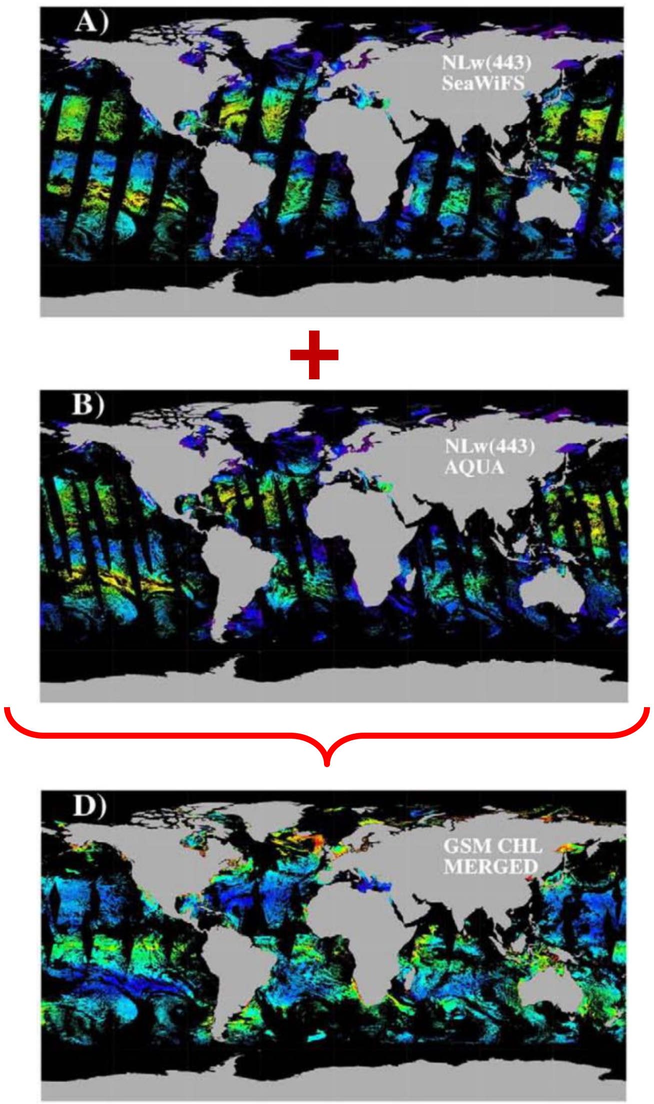
2002 - present



Ocean Bandsets

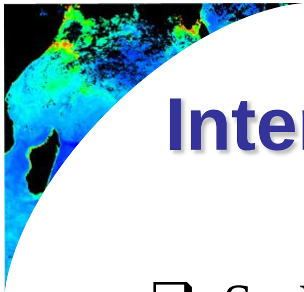


Key A-Train Contributions



- *Ecosystem stocks, composition, and change*
  - Continuation of heritage products
  - Improved global coverage
  - Linking ecosystem change to forcings
  - Partitioning carbon pools (multi-platform)
- *Constraints on productivity*
  - Physiological limitation by specific resources (e.g., nutrients)
  - Phytoplankton growth rates (multi-platform)
- *The complex ocean margins*
  - Advanced turbid water retrievals
  - Land-ocean materials exchange
  - Biomass in optically complex waters
  - Tracking unique algal groups

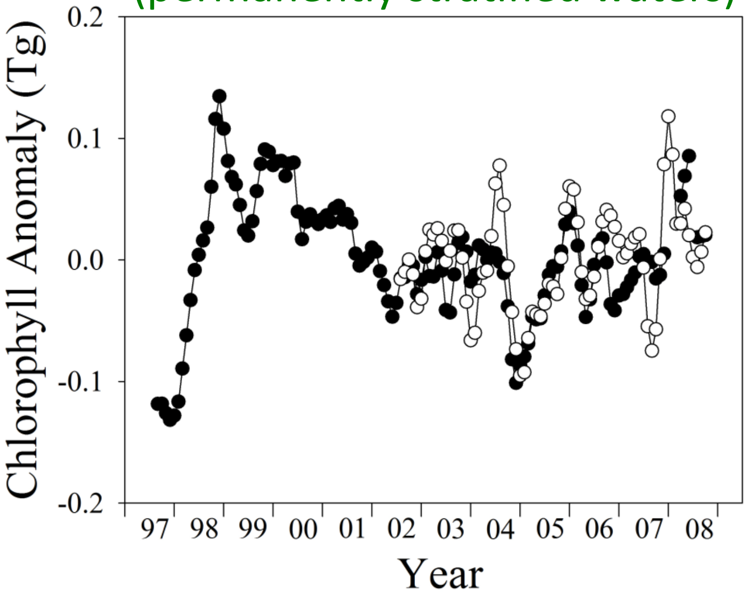
Merged satellite ocean color data products using a bio-optical model: Characteristics, benefits and issues
Remote Sensing of Environment 114 (2010) 1791–1804
Stéphane Maritorena [a,*], Odile Hembise Fanton d'Andon [b], Antoine Mangin [b], David A. Siegel



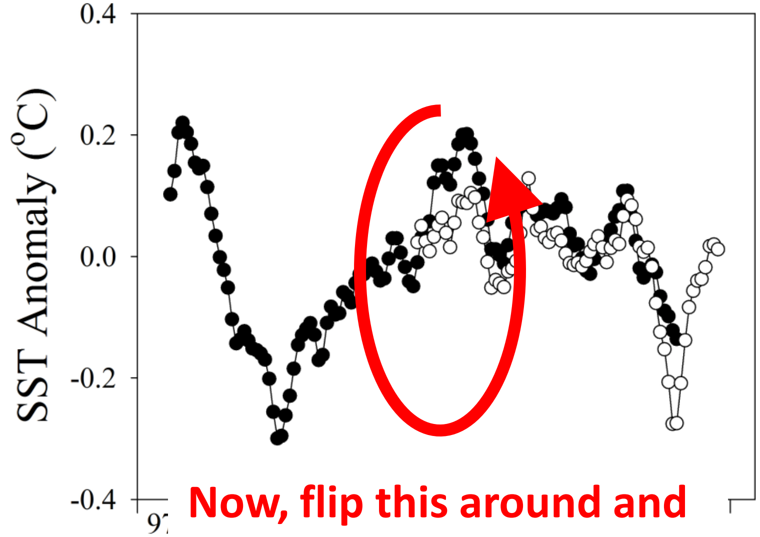
Inter-sensor Comparison

- ❑ SeaWiFS and MODIS-Aqua give similar chlorophyll anomaly trends
- ❑ AVHRR and MODIS-Aqua give similar SST anomaly trends
- ❑ MODIS-Aqua has allowed continuation of record despite SeaWiFS data gaps since 2008

Mid/Low-latitude Chlorophyll
(permanently stratified waters)



Sea Surface Temperature

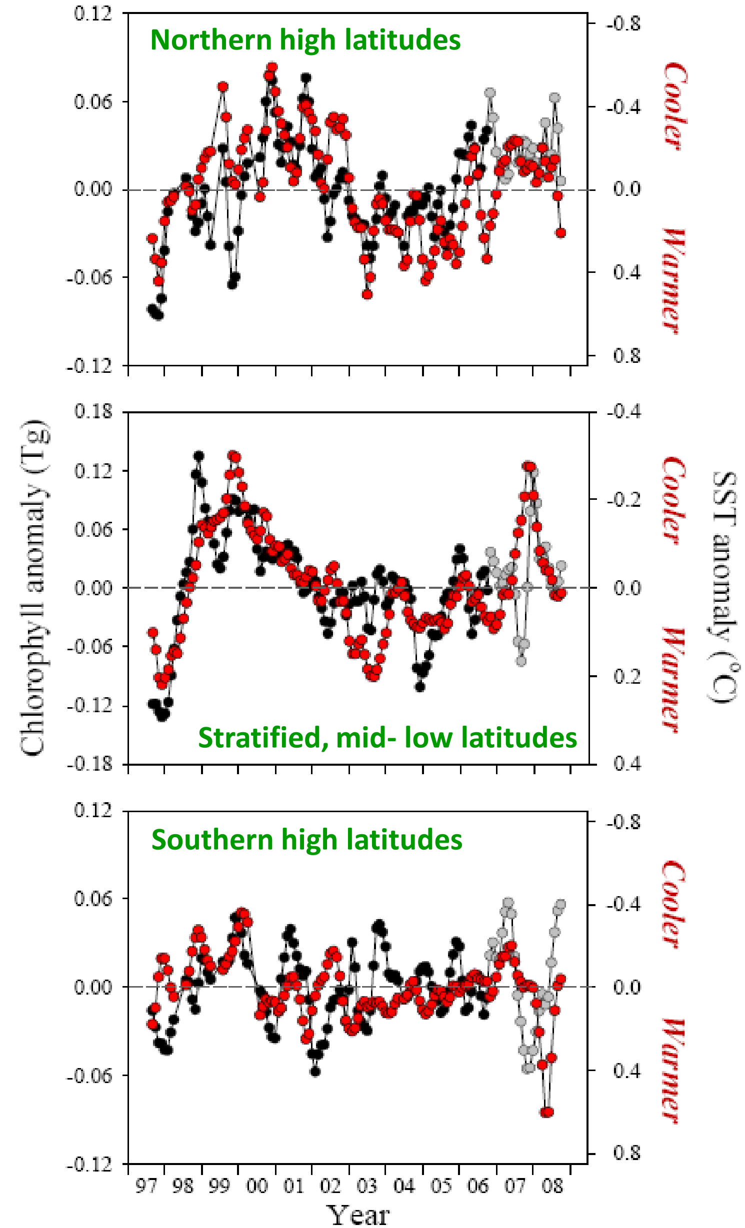


Now, flip this around and combine the two graphs…

Ecosystem Change

Observation: From regional to global scale, changes in satellite chlorophyll products are clearly linked changes in the physical environment (e.g., SST, stratification)

Value: The satellite record gives insight on ocean ecosystem responses to future ocean warming (cooling)

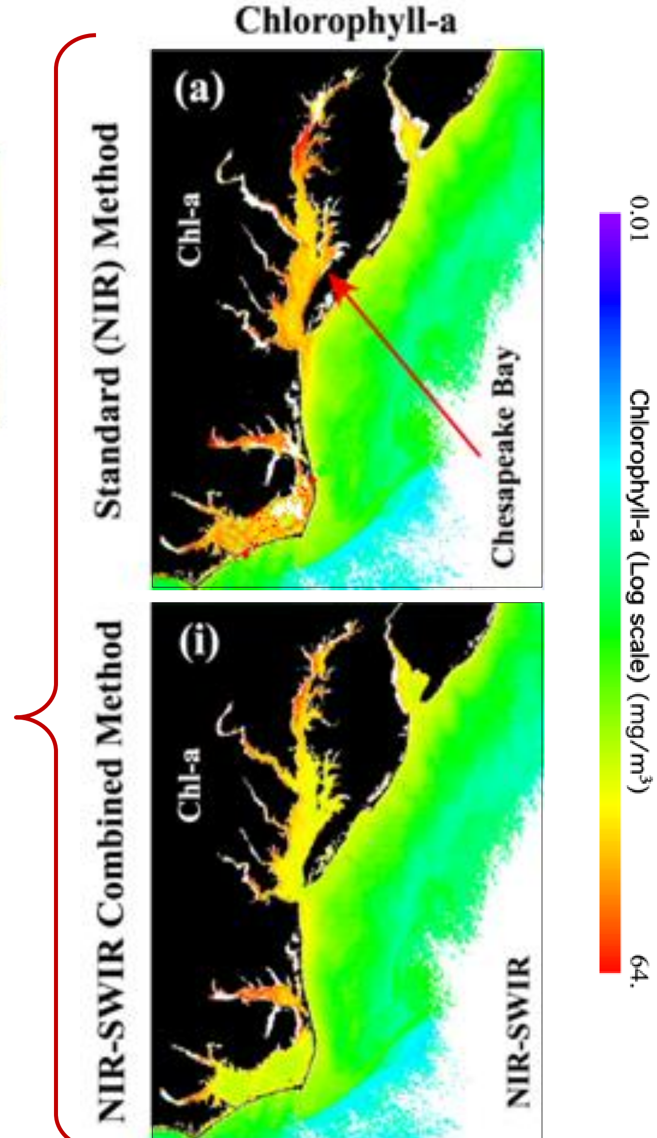


Ocean Margins and Inland Waters

Turbid Water Retrievals

- MODIS-Aqua bands in the Short-Wave InfraRed (SWIR) have significantly improved retrievals in turbid coastal regions

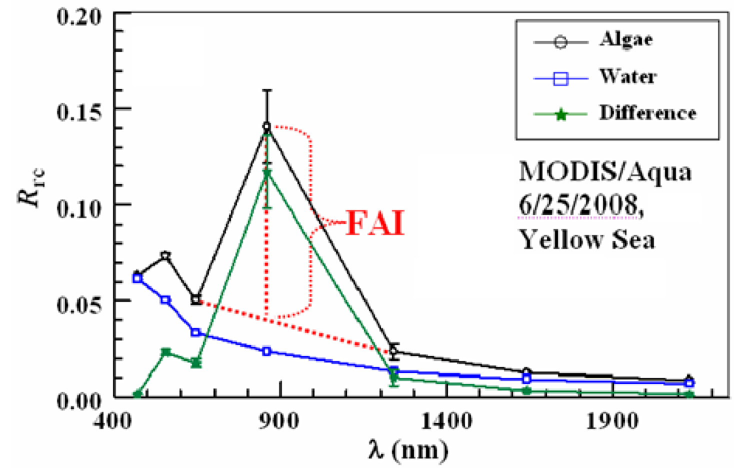
Wide variation in optical properties of natural waters

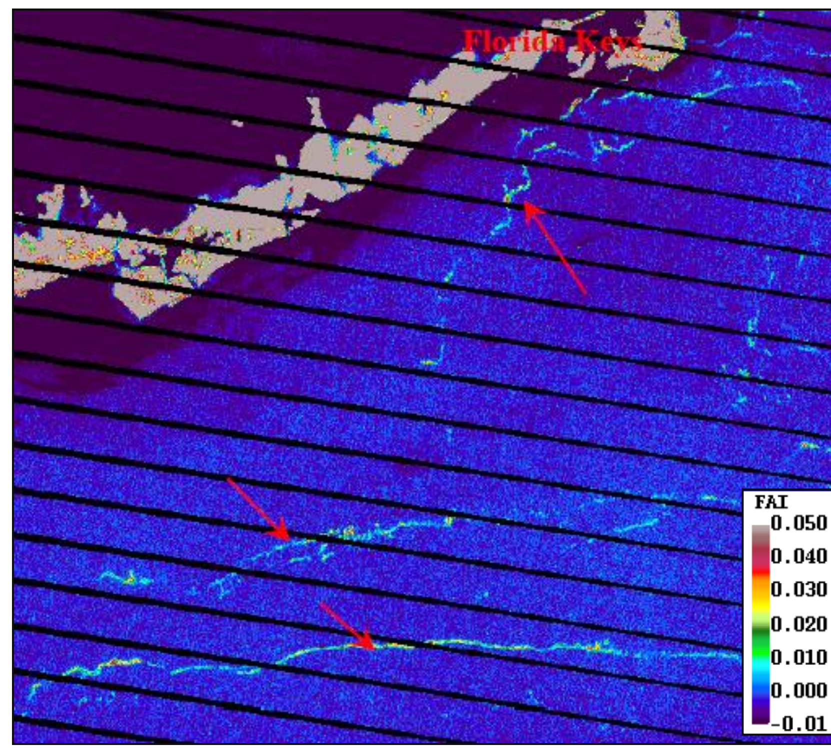


From: Wang, M. and W. Shi (2007) *Optics Express*, **15**, 15722-15733.

Unique Algal Groups

❑ MODIS-Aqua band set has been used to develop a 'Floating Algal Index' (FAI) – essentially a 'red-edge' algorithm – that can be used to monitor unique algal groups such as *Sargasso Weed*



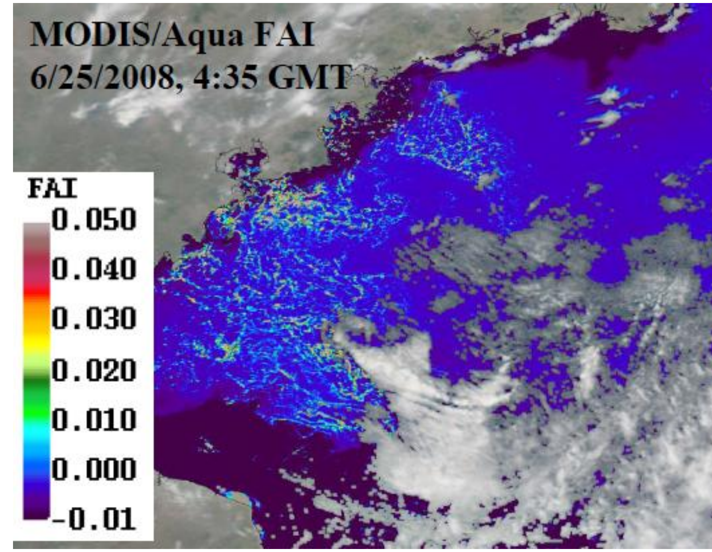


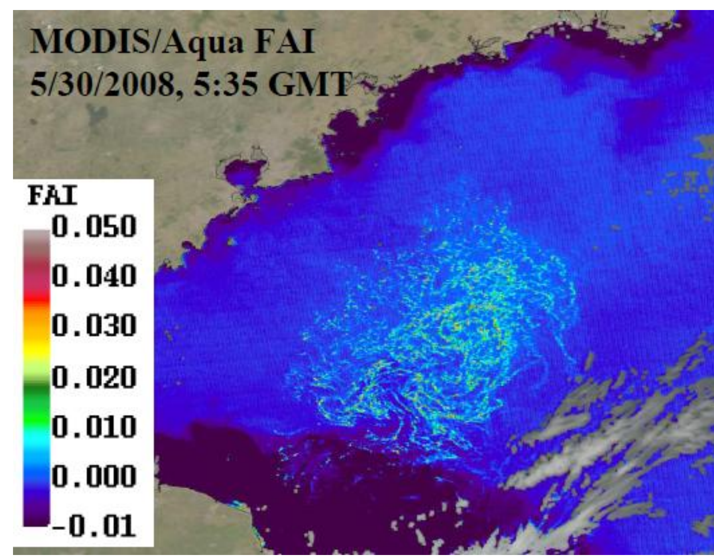
Graphs, images, & results from Chuanmin Hu, Univ. South Florida

Understanding Blooms

❑ Using the FAI algorithm and MODIS-Aqua data, the origins of a massive algal bloom in coastal China could be determined and linked to changing aquaculture practices

Qingdao, China, 2008

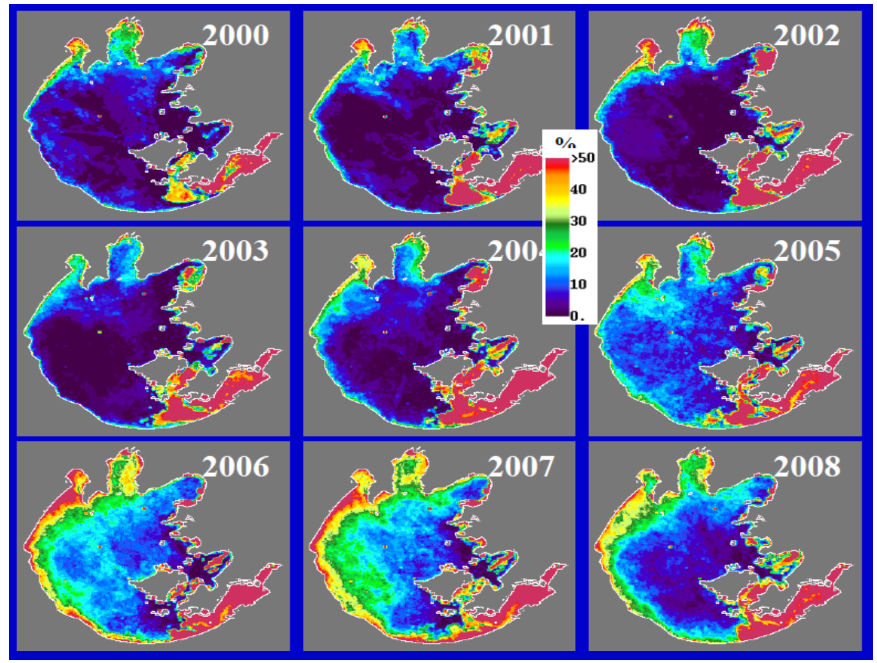


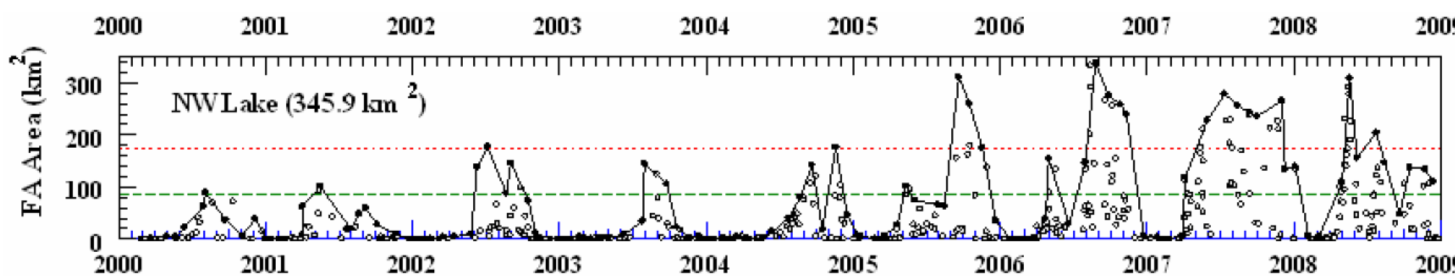


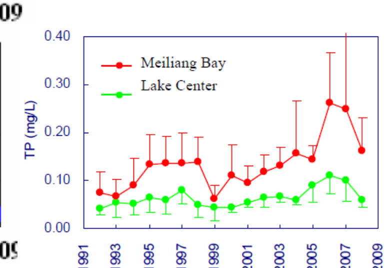
Graphs, images, & results from Chuanmin Hu, Univ. South Florida

Understanding Blooms

- Using the FAI algorithm and MODIS-Terra data, changes in inland noxious algal blooms in China could be monitored and linked to changing nutrient inputs



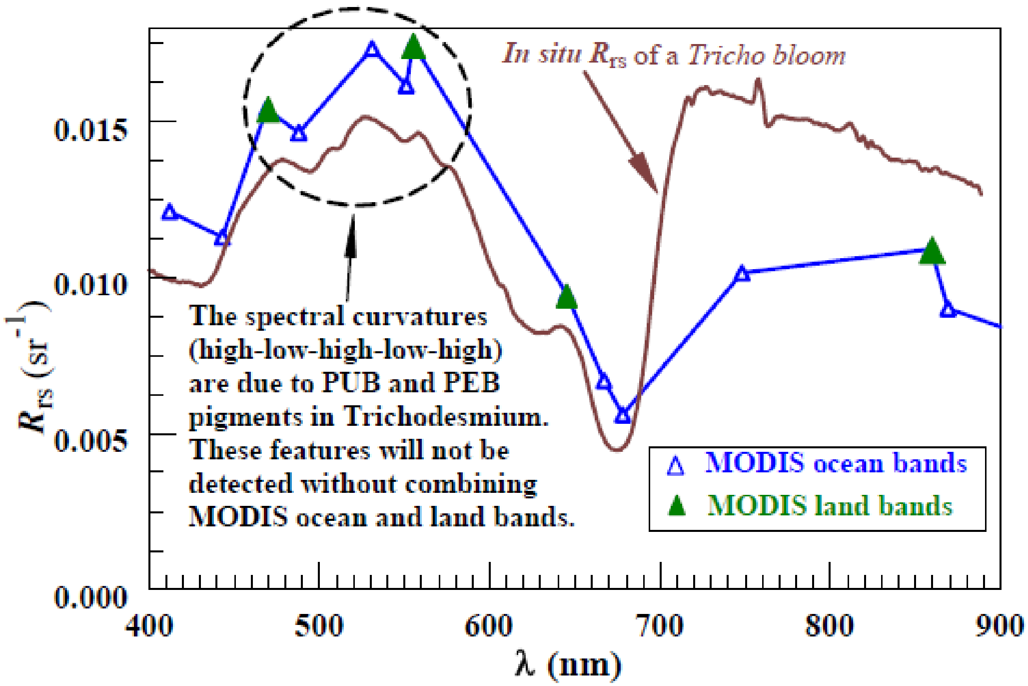


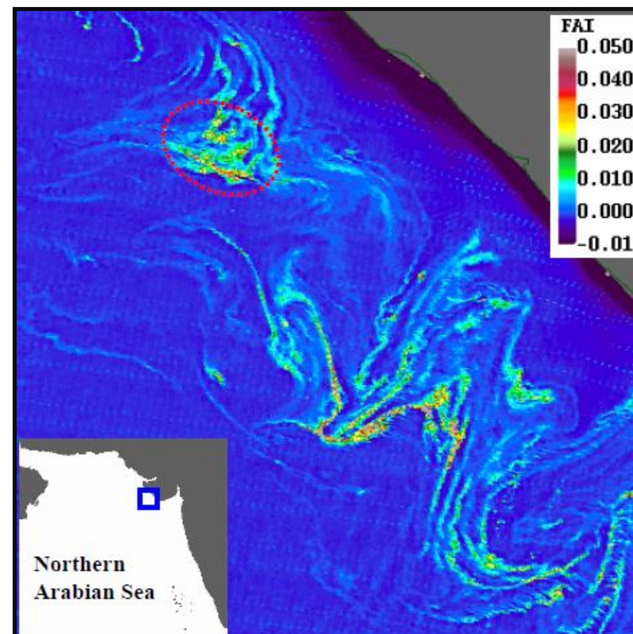


Graphs, images, & results from Chuanmin Hu, Univ. South Florida

Unique Algal Groups

- Combining MODIS-Aqua ocean and land bands has allowed detection of surface *Trichodesmium* blooms - a key nitrogen fixing organism in the ocean





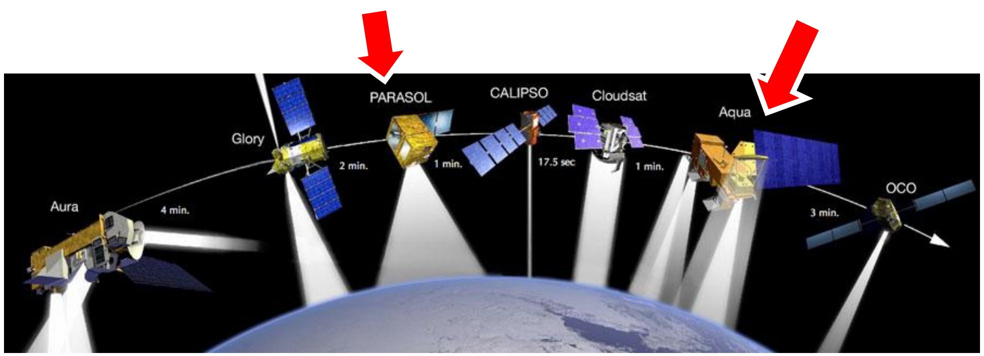
Graphs, images, & results from Chuanmin Hu, Univ. South Florida

Partitioning Carbon Pools

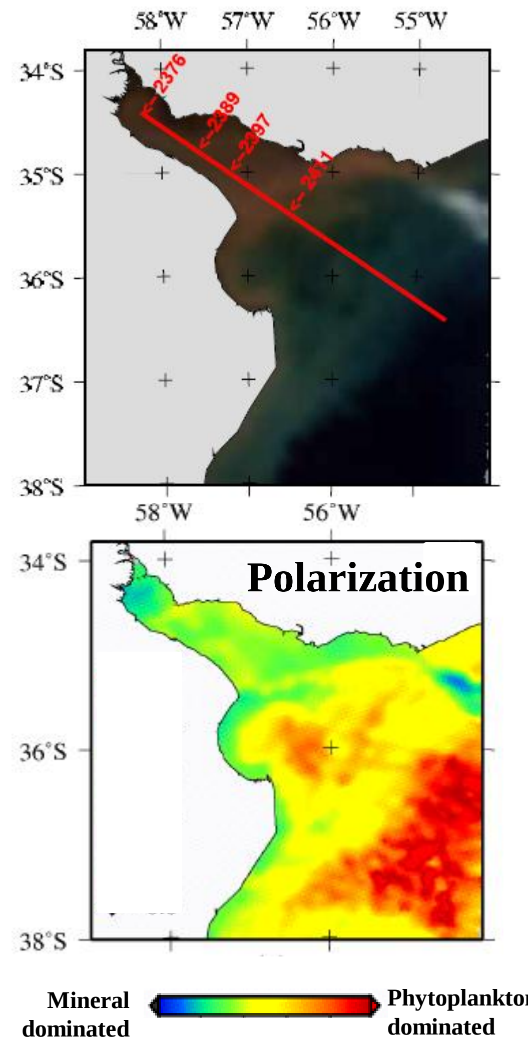
- Carbon dynamics are influenced by partitioning of stocks between biotic and mineral particles

- The two classes have different polarization signatures

- Combining ocean color data with polarimeter data from POLDER allows carbon stocks to be distinguished, yielding information on *land-ocean exchange and coastal-to-open ocean carbon flow*



Rio de la Plata

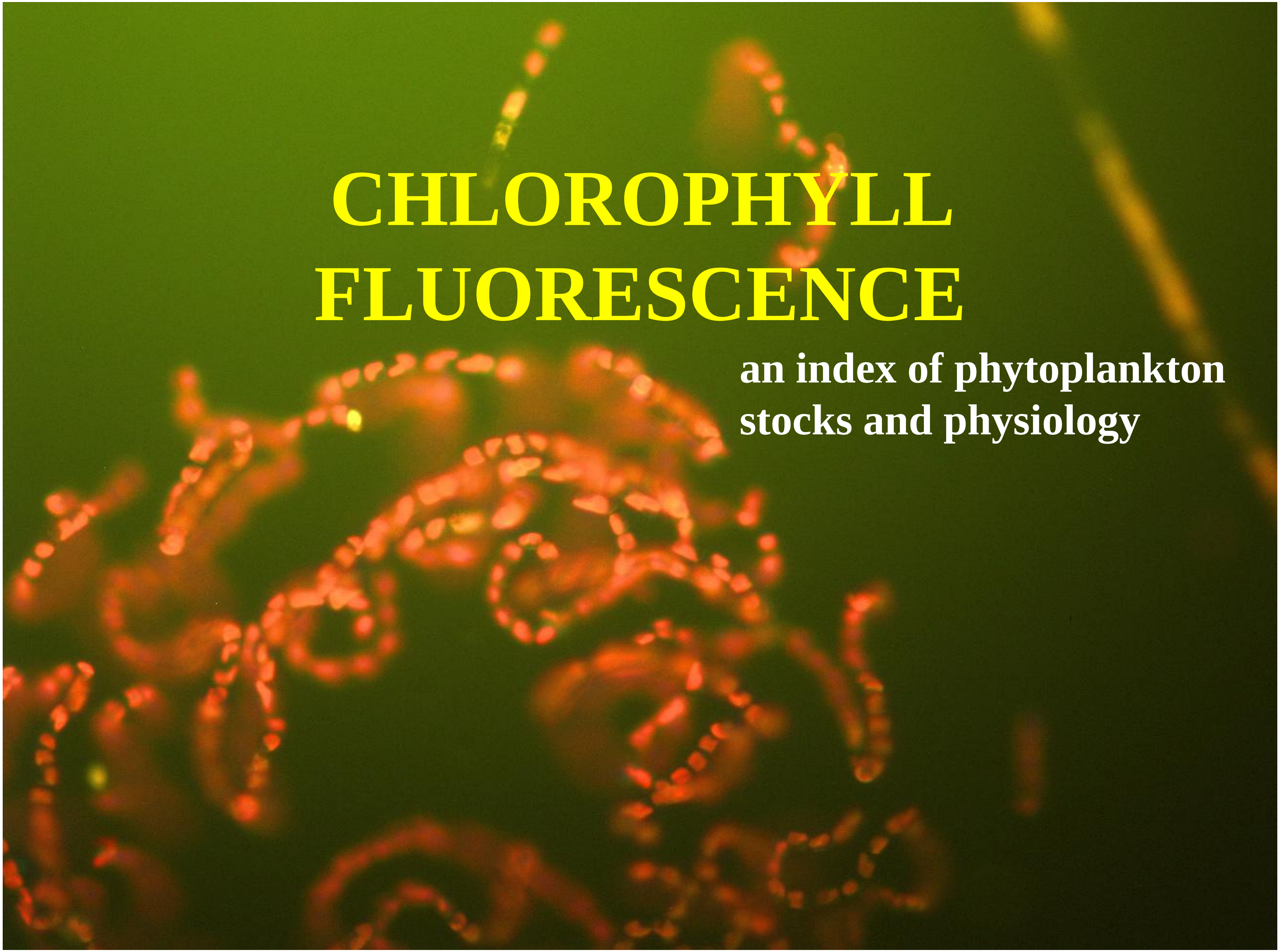


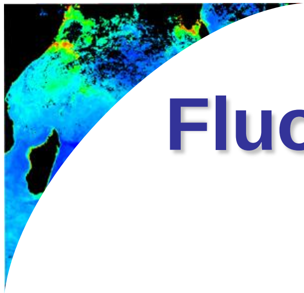
Hubert Loisel[1], Lucile Duforet[1], David Dessailly[1], Malik Chami[2], and Philippe Dubuisson[3]

18 August 2008 / Vol. 16, No. 17 / OPTICS EXPRESS

CHLOROPHYLL FLUORESCENCE

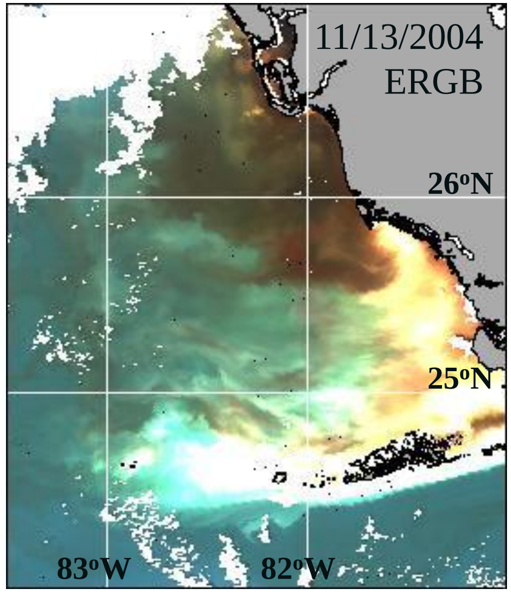
an index of phytoplankton stocks and physiology

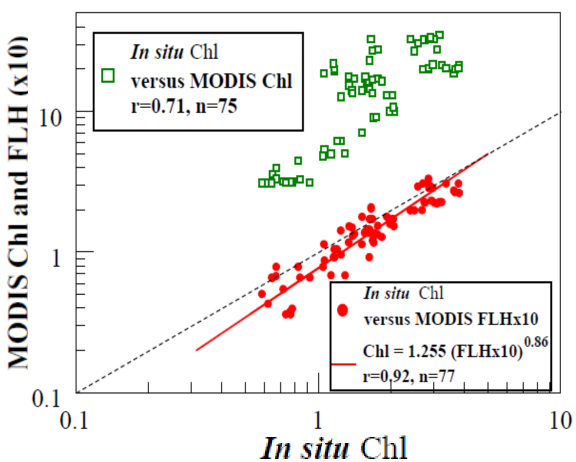


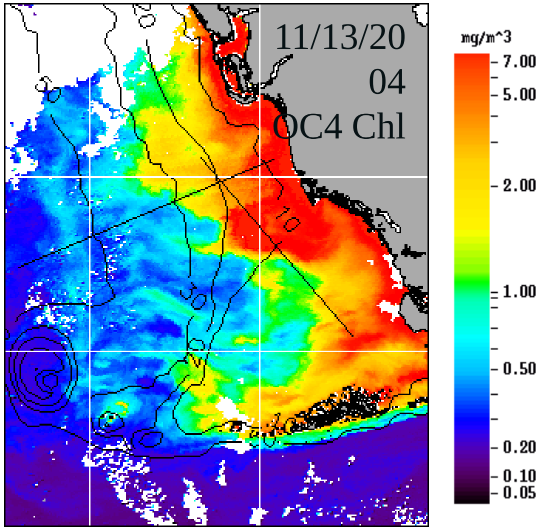


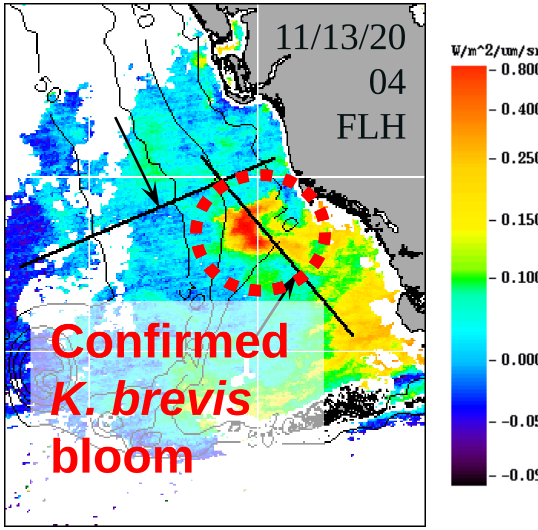
Fluorescence

- In optically-complex waters, fluorescence can provide a better estimate of phytoplankton stocks than standard algorithms





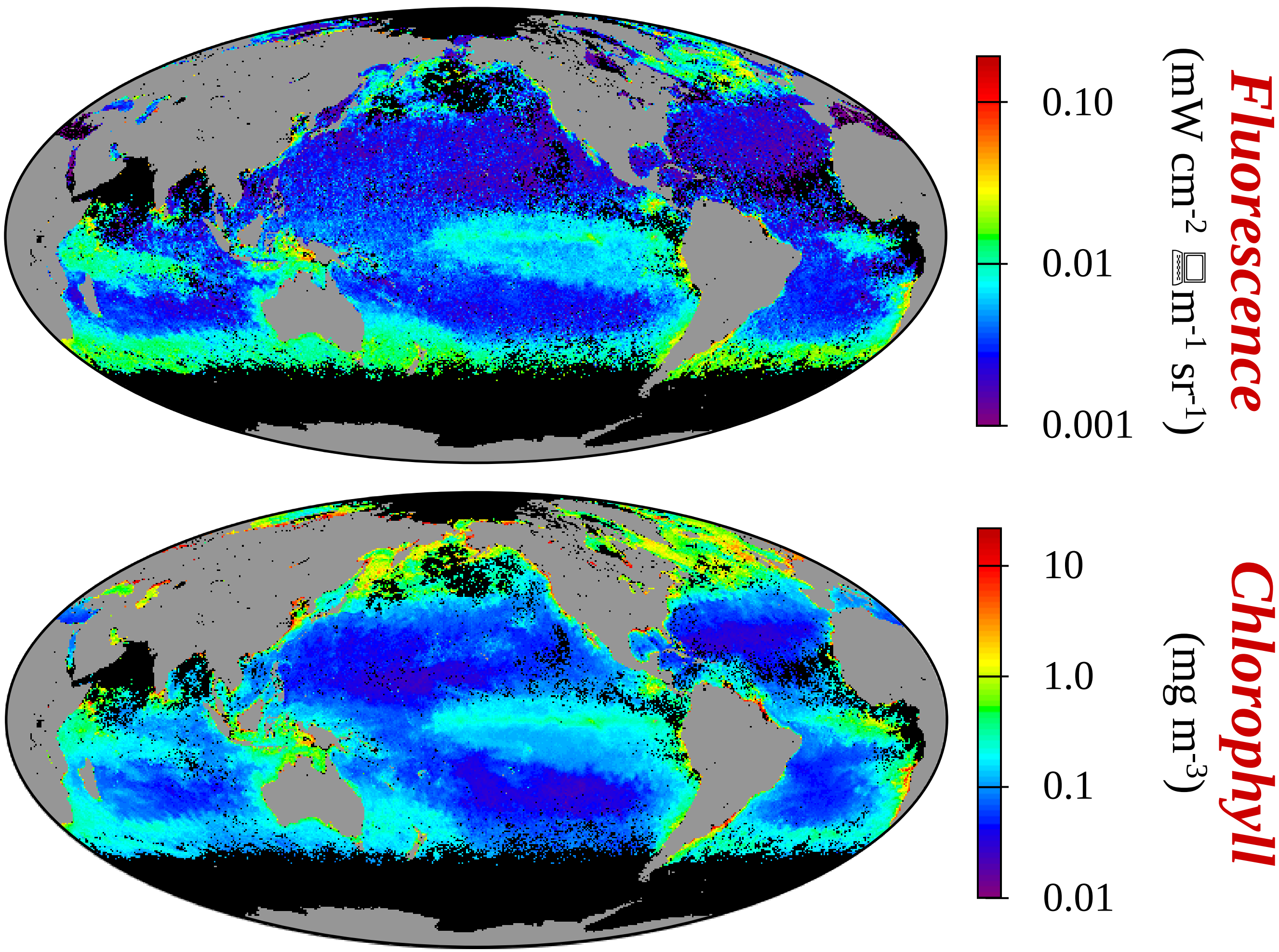




Graphs, images, & results from Chuanmin Hu, Univ. South Florida

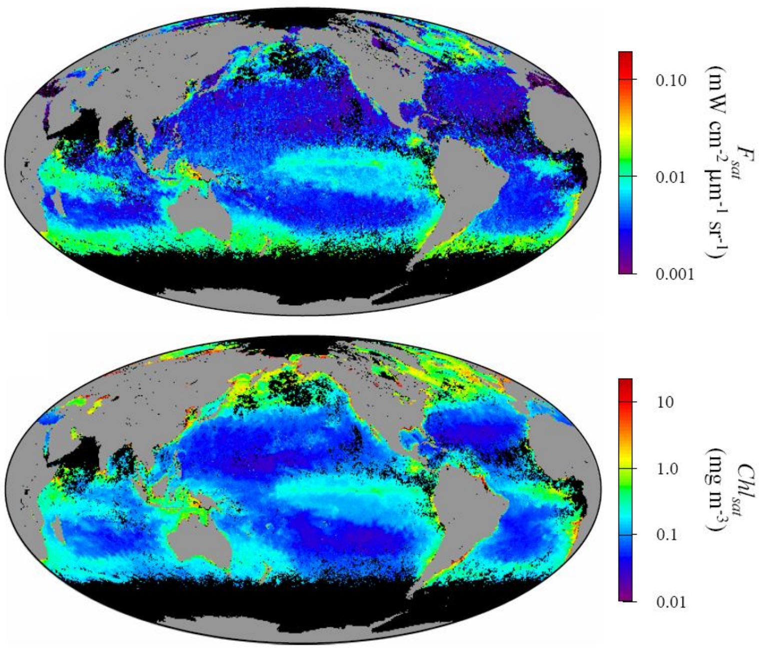
Fluorescence

❑ Fluorescence also registers variations in phytoplankton pigments globally, but the relationship is more complex than in specific regions

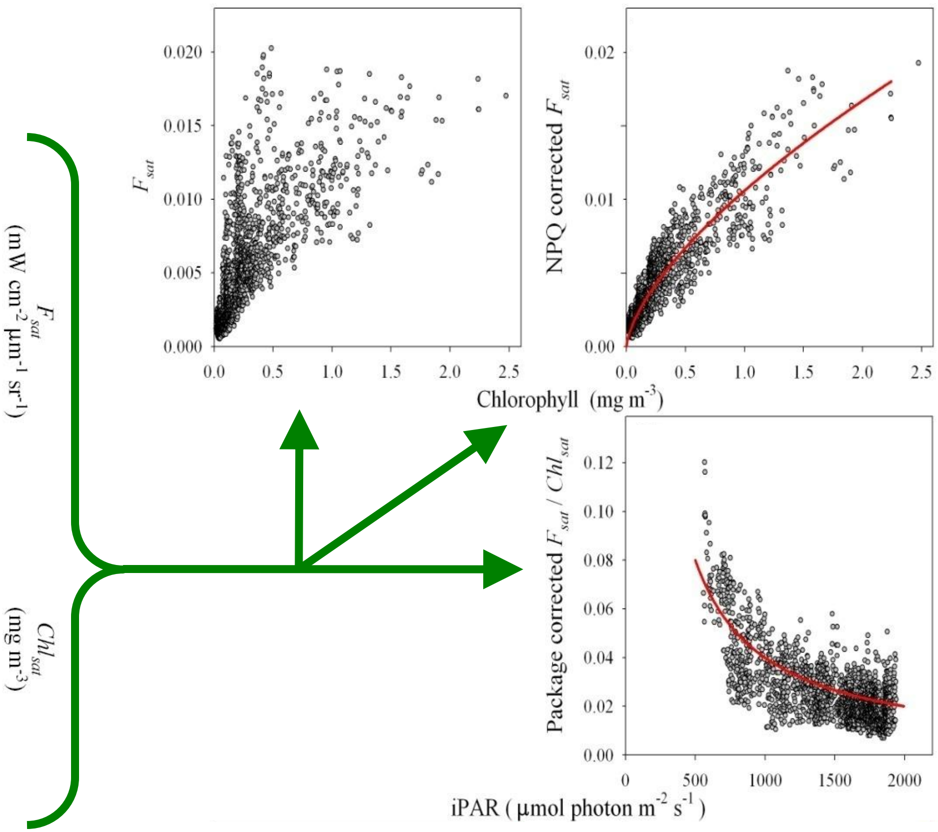


Fluorescence

fluorescence



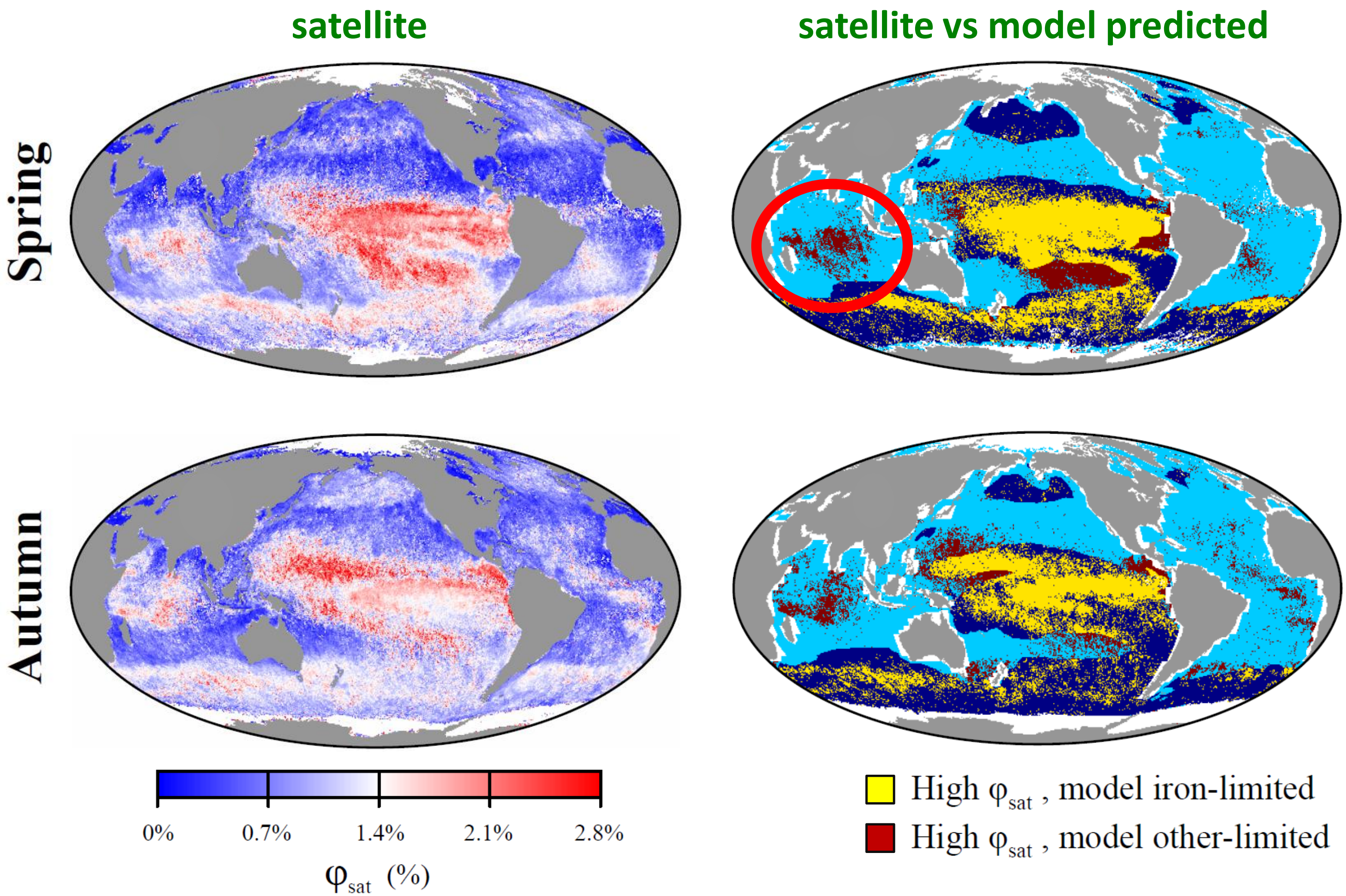
chlorophyll



Any additional physiological information resides in this remaining scatter

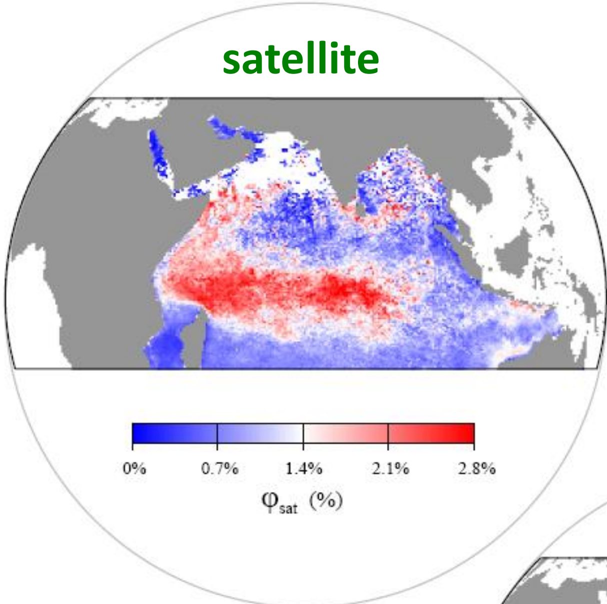
Fluorescence

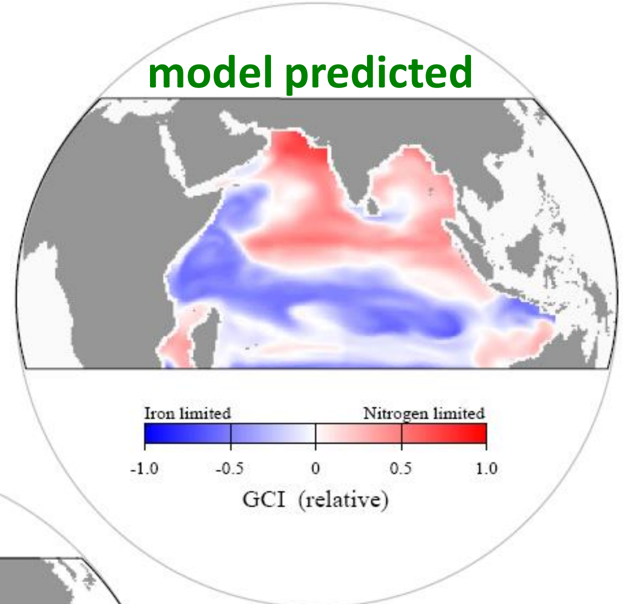
- The dominant physiological signal in fluorescence data is ***iron stress***

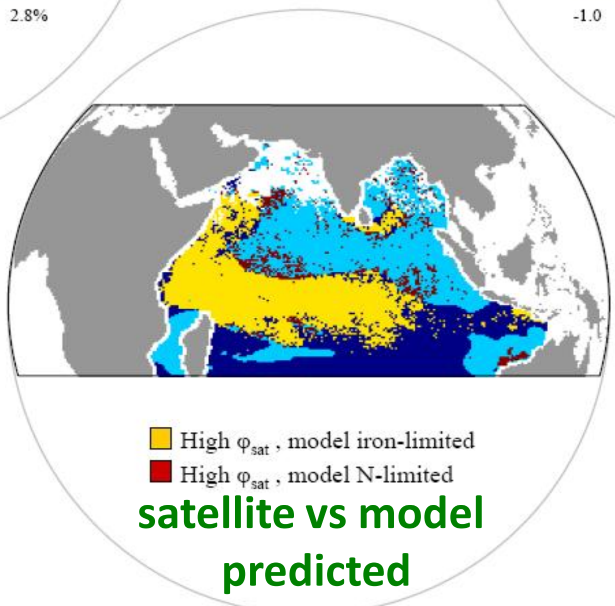


Fluorescence

- ❑ MODIS fluorescence data provided first observational evidence for iron stress in the Indian Ocean



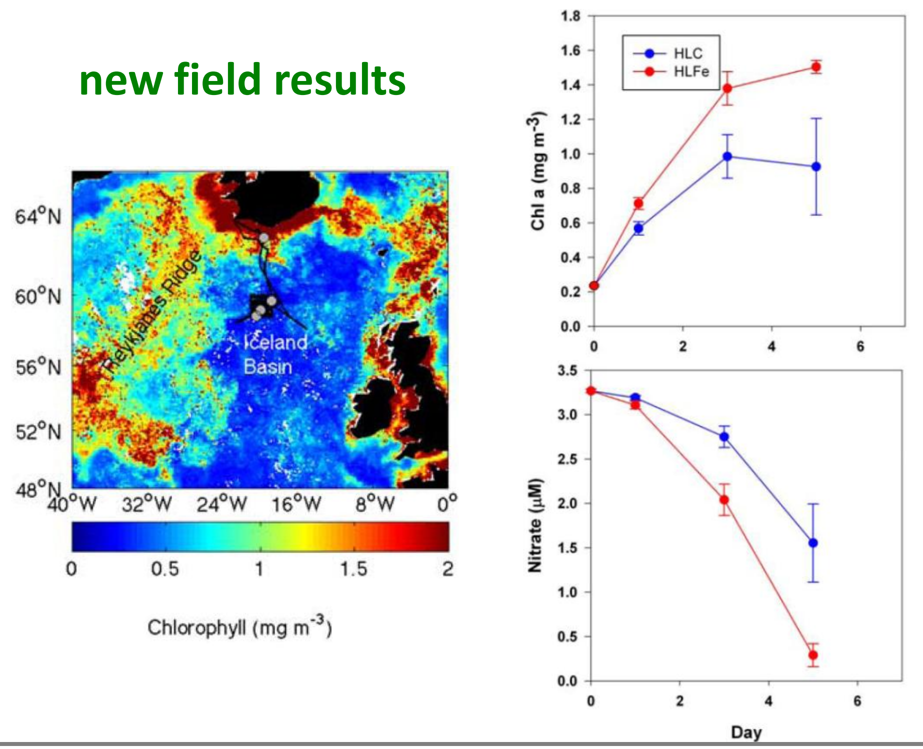




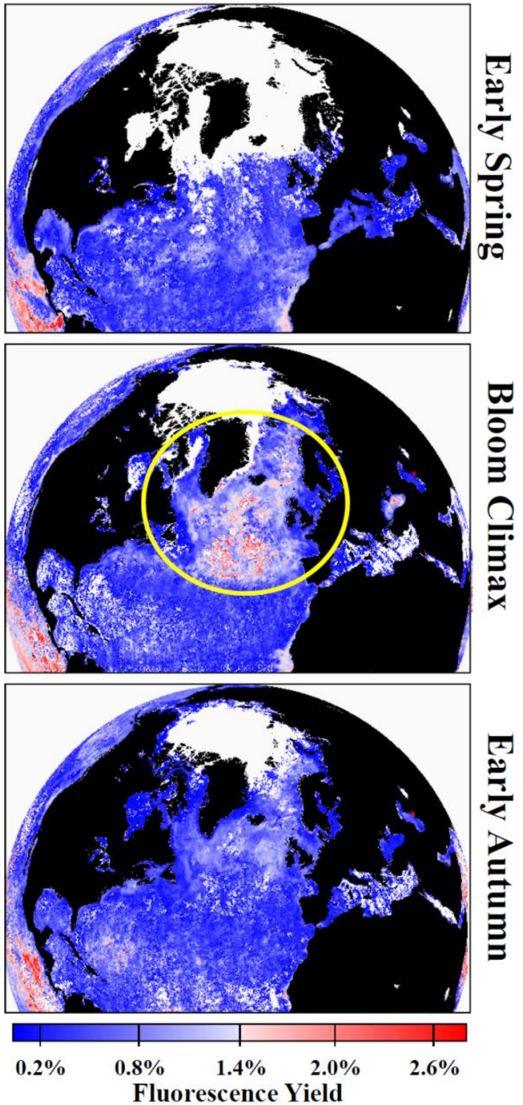
Fluorescence

❑ MODIS fluorescence & field data are also providing the first evidence of iron stress in the North Atlantic

new field results



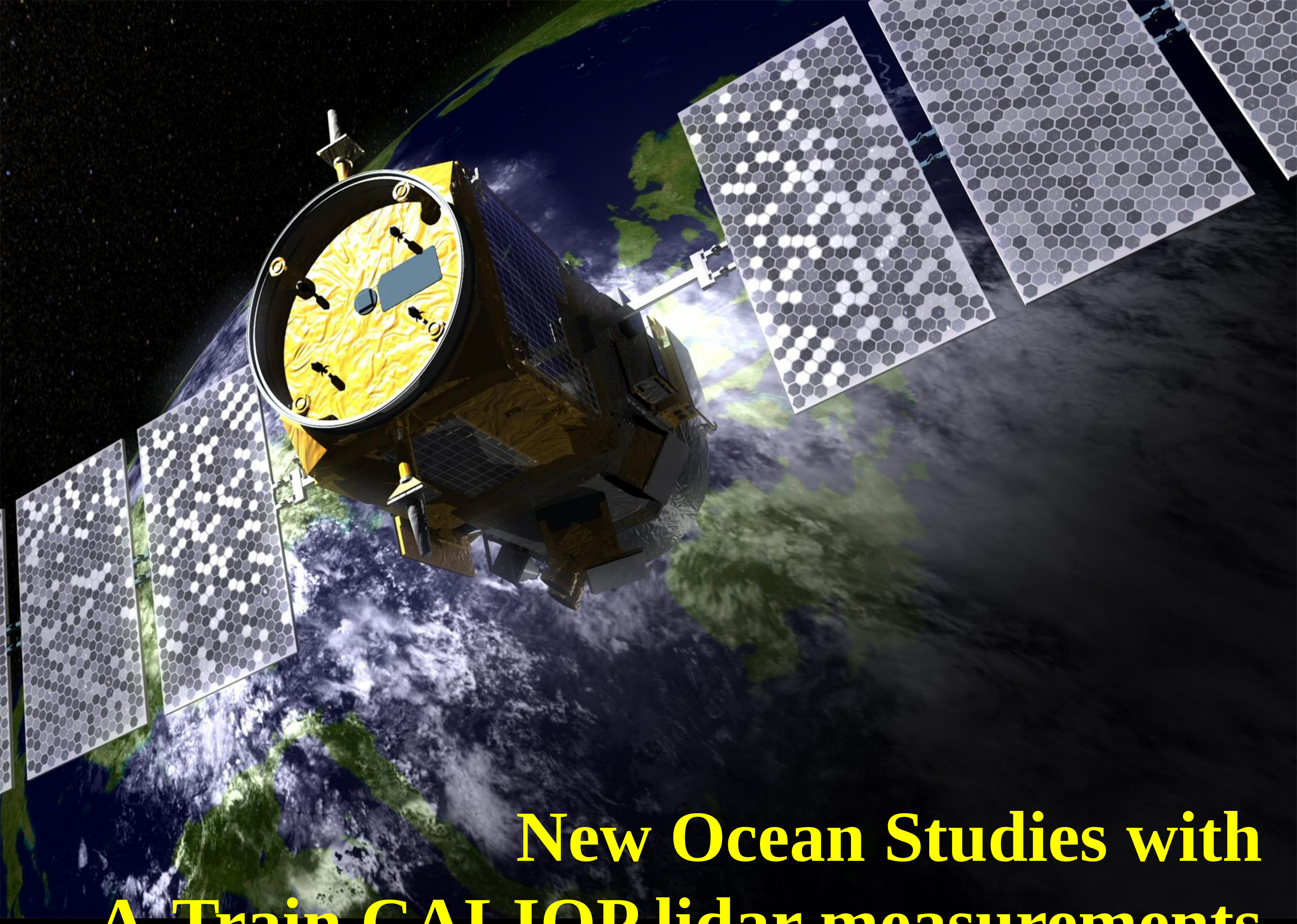
new satellite findings



Iron limitation of the postbloom phytoplankton communities in the Iceland Basin

GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 23, GB3001, doi:10.1029/2008GB003410, 2009

Maria C. Nielsdóttir,[1] Christopher Mark Moore,[1] Richard Sanders,[1] Daria J. Hinz,[1] and Eric P. Achterberg[1]



New Ocean Studies with A-Train CALIOP lidar measurements

A Role for Lidar

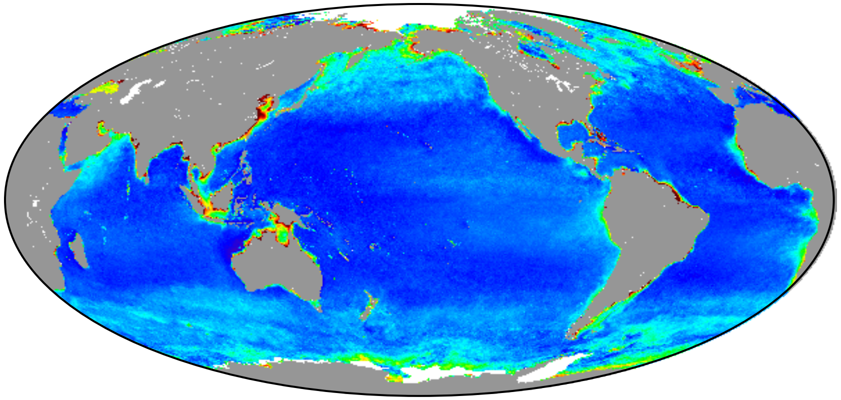
- ❑ Phytoplankton biomass (carbon) can be related to the backscatter coefficient

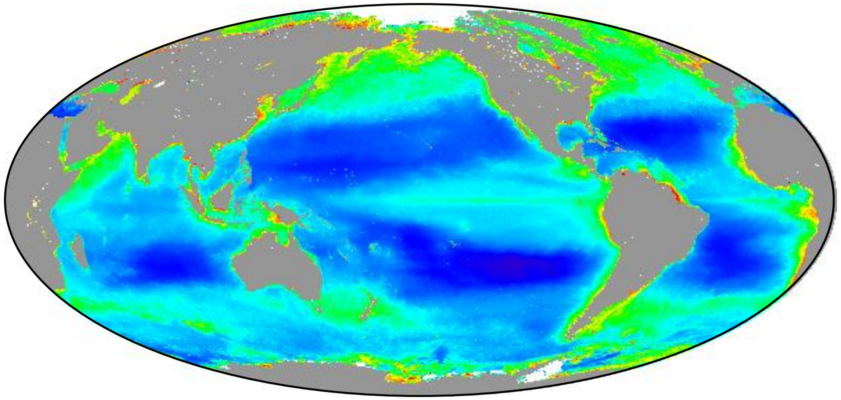
- ❑ Having both carbon and chlorophyll data allows assessment of phytoplankton physiological status (health) and global ocean photosynthesis

- ❑ Current *biomass* estimates are based on ocean color inversion algorithms that rely on a variety of assumptions

- ❑ Lidar measurements could provide an alternative, active measure of light scattering – thus phytoplankton biomass

Phytoplankton Carbon





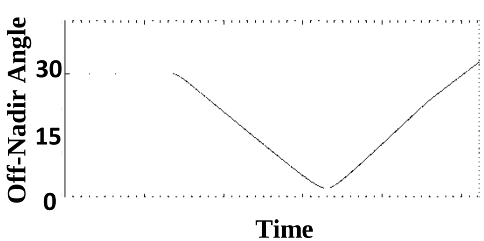
Phytoplankton Chlorophyll

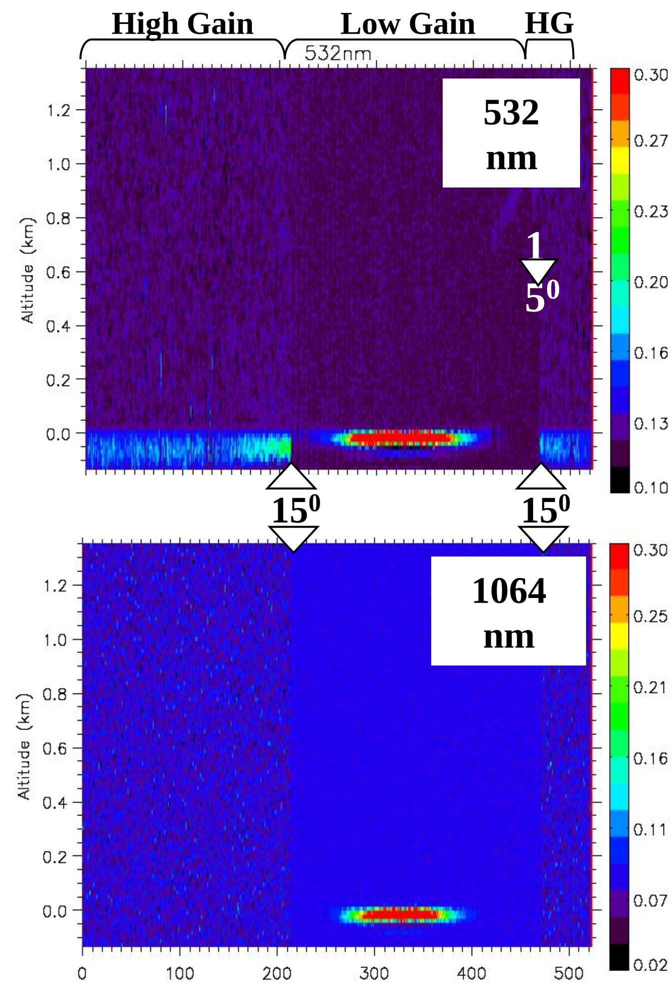
Images & analyses by Toby Westberry, Oregon State University

Lidar Oceanography

Lidar In-space Technology Experiment (LITE)

- 3-wavelength Nd-Yg lidar
- Space Shuttle in 1994
- Multi-angle (+/-30^0) maneuvers over Lake Superior and Gulf of California

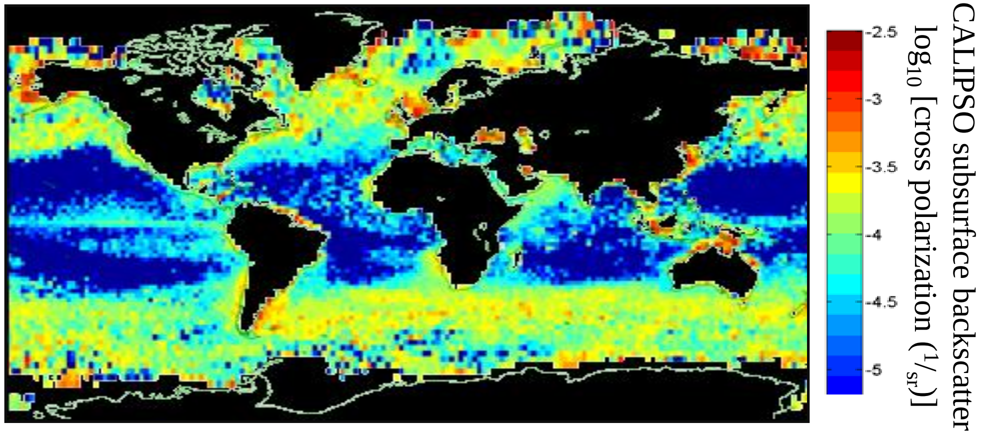




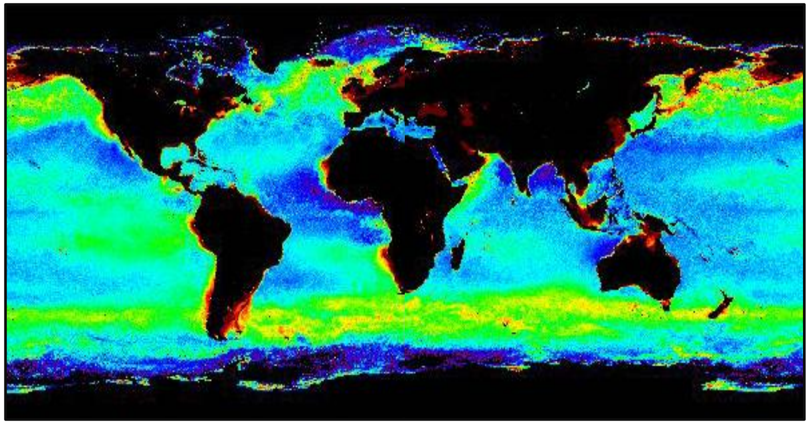
Lidar Oceanography

- ❑ CALIPSO-CALIOP lidar sub-surface particle scattering retrievals show similar global patterns and ocean color inversion retrievals
- ❑ Lidar data also show seasonal cycles consistent with known oceanographic features (e.g., seasonal high latitude blooms)
- ❑ Lidar data may provide an independent ‘test bed’ for inversion results or a constraint for inversion solutions

Lidar results



Inversion results



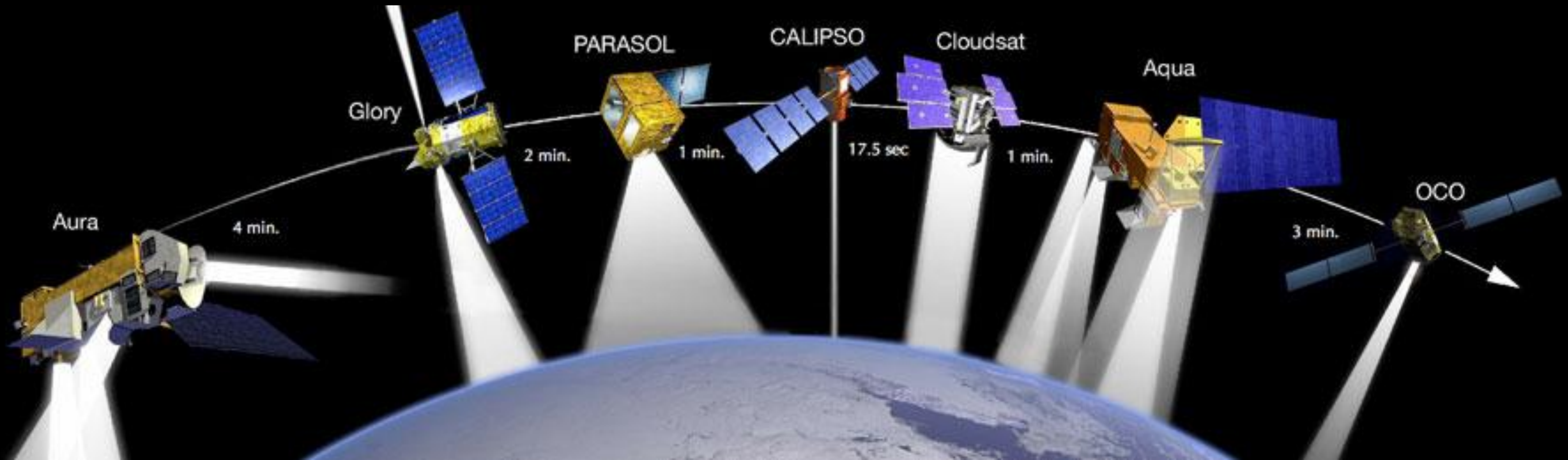
Graphs, images, & results from Yong Hu, NASA Langley

Ocean Research with the A-Train

- **Expanded observational capabilities of MODIS-Aqua have advanced understanding of ocean ecosystems from the regional to global scale, in particular regarding phytoplankton blooms and physiology**

- **The combined use of MODIS-Aqua, CALIPSO, and PARASOL data has opened new roads for assessing ocean carbon stocks, characterizing their composition, and monitoring their fate**

- **Additional opportunities exist for significantly improving ocean retrievals by merging MODIS-Aqua data with A-Train atmospheric data**




Thank You

Paths for Scientific Advances

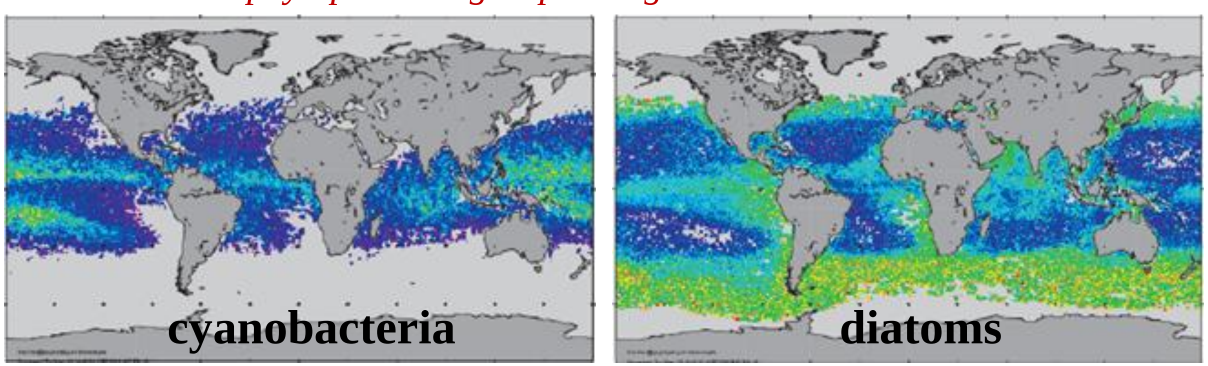
❑ Separation of absorption by phytoplankton pigments and colored dissolved organic material remains a major issue. **Approach**: expansion into the near ultraviolet

❑ Inversion algorithms currently assume a given spectral shape for phytoplankton absorption. **Approach**: derive phytoplankton absorption spectrum from higher spectral resolution measurements

❑ Inversions assume a spectral shape for backscattering. **Approach**: increase spectral resolution of measurements in the 'green-yellow' region of minimum pigment absorption

❑ Current assessments of phytoplankton groups are limited by heritage spectral bands. **Approach**: high spectral resolution from near-UV through visible allows derivative analyses of specific, taxonomically-unique pigment absorption features.

*phytoplankton groups using SCIAMACHY**



* 960 km swath width (6 d global coverage)
UV to NIR at high resolution (<1 nm)
30 km x 30 km pixel size